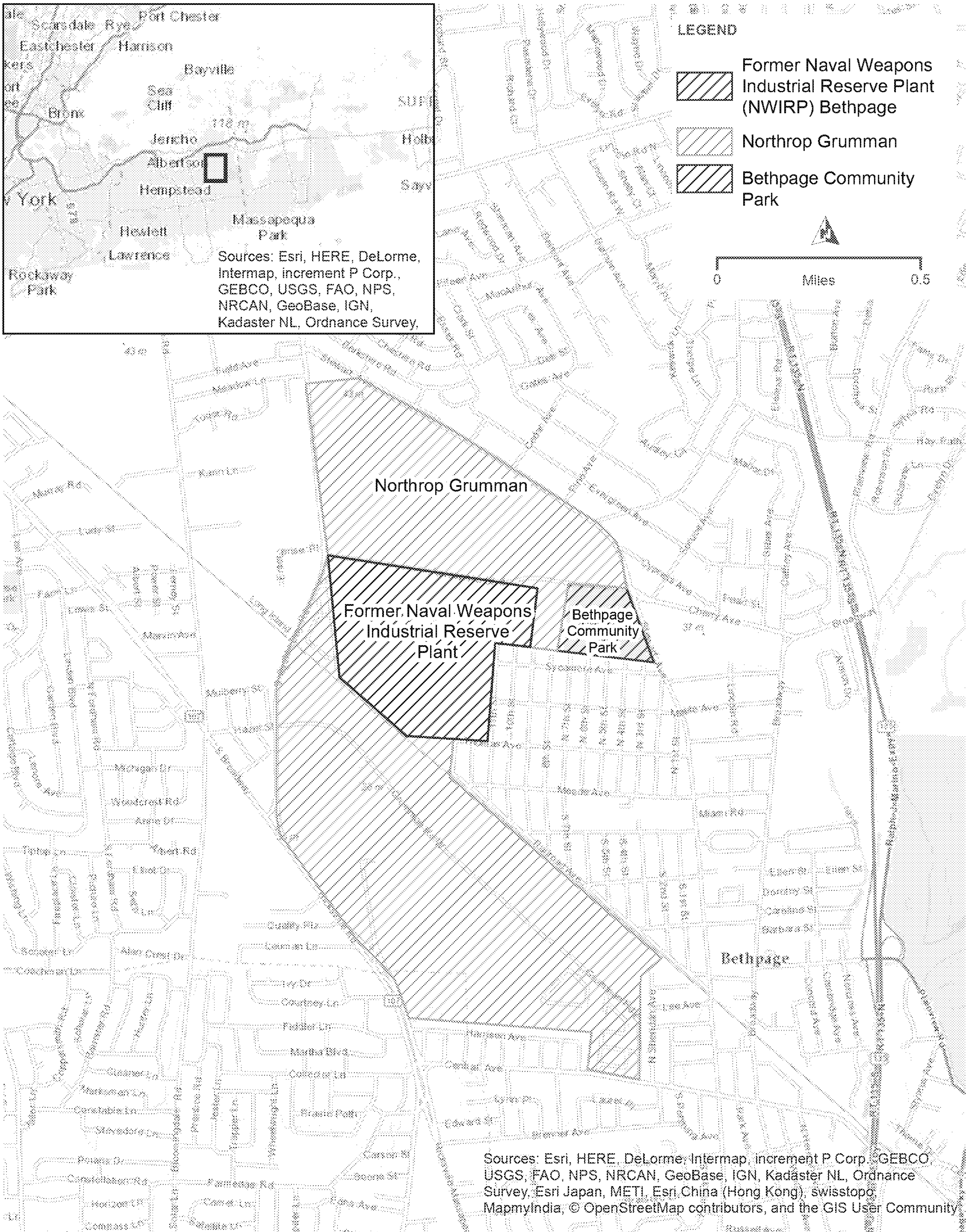
FIGURES



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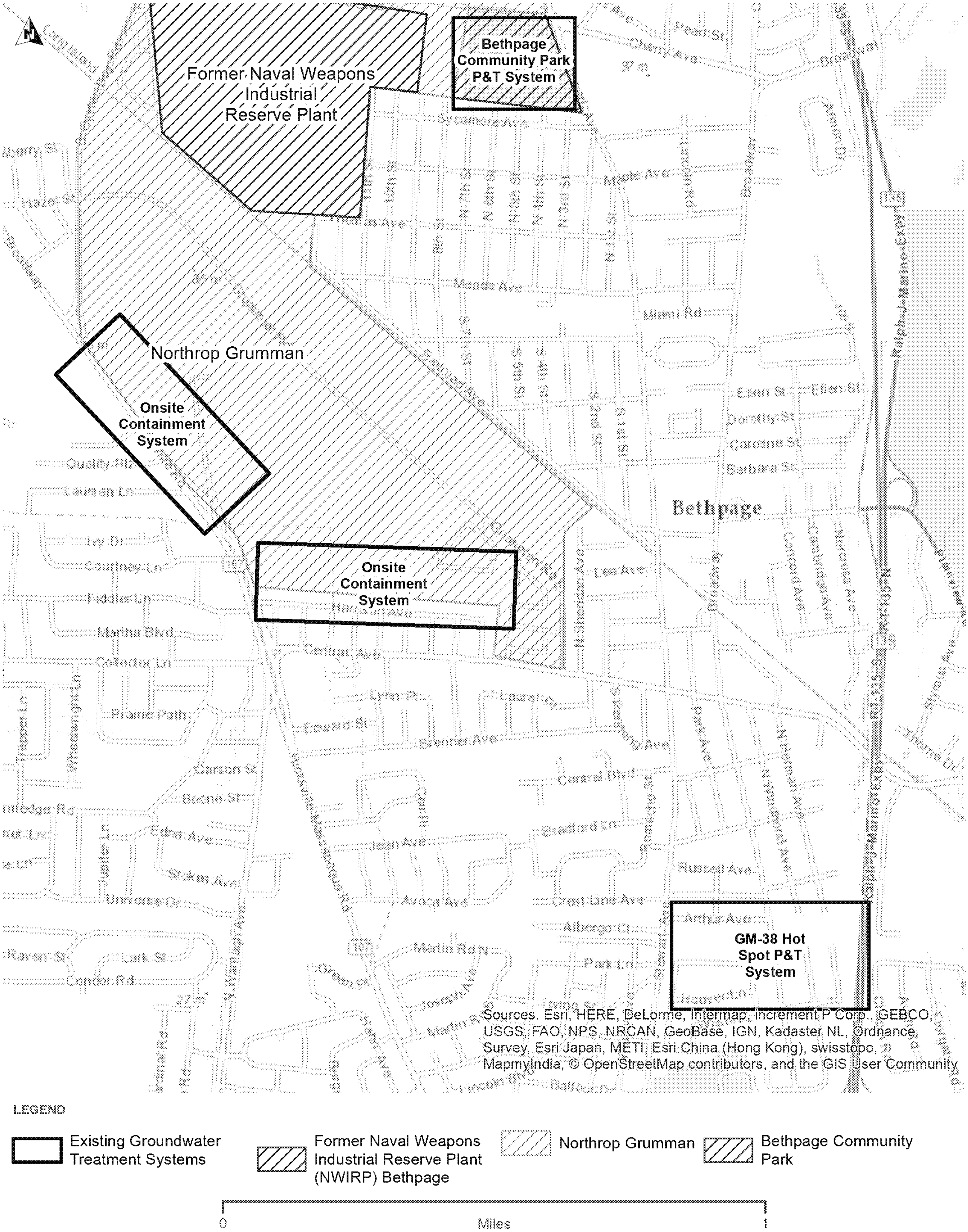
Site Location Map

NYSDEC Site #130003

Figure 1-1

PATH: Z:\202315_NEW YORK STATE DEPT OF ENVIRONMENTAL CON\0256275_NYSDEC_ML_WA_23_NORTHGRUMMAN\GIS\MAP_DOCS\DRAFT\GRUMMAN_SITE_LOCATIONS_20150810.MXD

(REMEDIAL OPTIONS REPORT)



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Existing Groundwater Remediation Areas

NYSDEC Site #130003

Figure 1-2

PATH: Z:\202315_NEW YORK STATE DEPT OF ENVIRONMENTAL CON\10256276_NYSDEC_ML_WA_23_NORTHGRUMMAN\GIS\MAP_DOCS\DRAFT\GRUMMAN_EXISTING_GROUNDWATER_REMEDIATION_AREAS_20151011.MXD

(REMEDIAL OPTIONS REPORT)

System	Series	Geologic Units		Hydrogeologic Unit	Range of Thickness (feet)	Range of Altitude of Upper Surface, in feet above or below sea level
Quaternary	Holocene	Shore, beach Salt-Marsh deposits, and alluvium				
Quaternary	Pleistocene	Wisconsin Glaciation (Harbor Hill, Interstadial Marine, and Ronkonkoma Drift)	Till (ground terminal moraine) Outwash 20-foot Clay (marine)	Upper Glacial aquifer	0 to 450	Land Surface
Quaternary	Pleistocene	Sangamon Interglaciation	Gardiners Clay (marine)	Gardiners Clay	0 to 320	-40 to -250
Quaternary	Pleistocene	Pre-Wisconsin Glaciation (Illinoian)	Jameco Gravel	Jameco aquifer	0 to 185	-90 to -450
Tertiary	Pliocene	Mannetto Gravel		Unsaturated	0-220	0 to -120
Cretaceous	Upper Cretaceous	Matawan Group - Magothy Formation (undifferentiated)		Magothy aquifer	0 to 800	200 to -350
Cretaceous	Upper Cretaceous	Raritan Formation	Clay member	Raritan Clay confining unit	0 to 300	-100 to -1,000
Cretaceous	Upper Cretaceous	Raritan Formation	Lloyd sand member	Lloyd aquifer	0 to 300	-200 to -1,200
Precambrian		Crystaline Bedrock		Bedrock	--	-400 to -1,500

Modified from: Isbister, J., 1966, Geology and Hydrology of Northeastern Nassau County, Long Island, New York: U.S. Geological Survey Water-Supply Paper 1825, 89 p.

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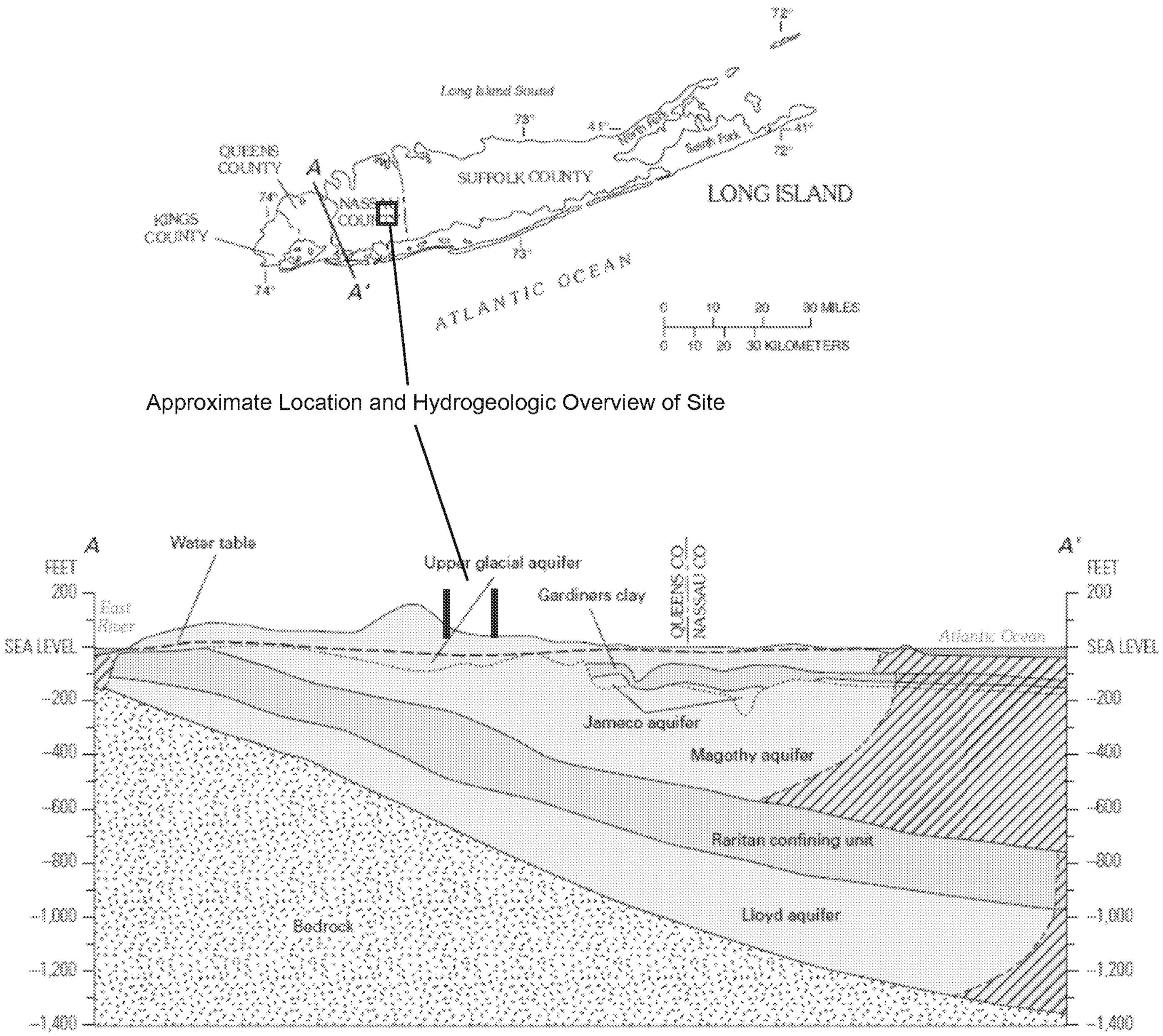
Stratigraphic Column of the Geology of Nassau County

NYSDEC Site #130003

Figure 1-3



Vertical Exaggeration: 30X

LEGEND

Area of salty ground water

Confining unit

Sea level refers to the National Geodetic Vertical Datum of 1929

Notes:

Figure modified from:

(1) Barlow, P. M., 2003, Ground Water in Freshwater-Saltwater Environments of the Atlantic Coast, U.S. Geological Survey Circular 1262, 121 p.

(2) Buxton, Herbert T.; Smolensky, Douglas A., 1999, Simulation of the effects of development of the ground-water flow system of Long IslandpW New York: U.S. Geological Survey Water-Resources Investigations Report 98-4069, 57 p.

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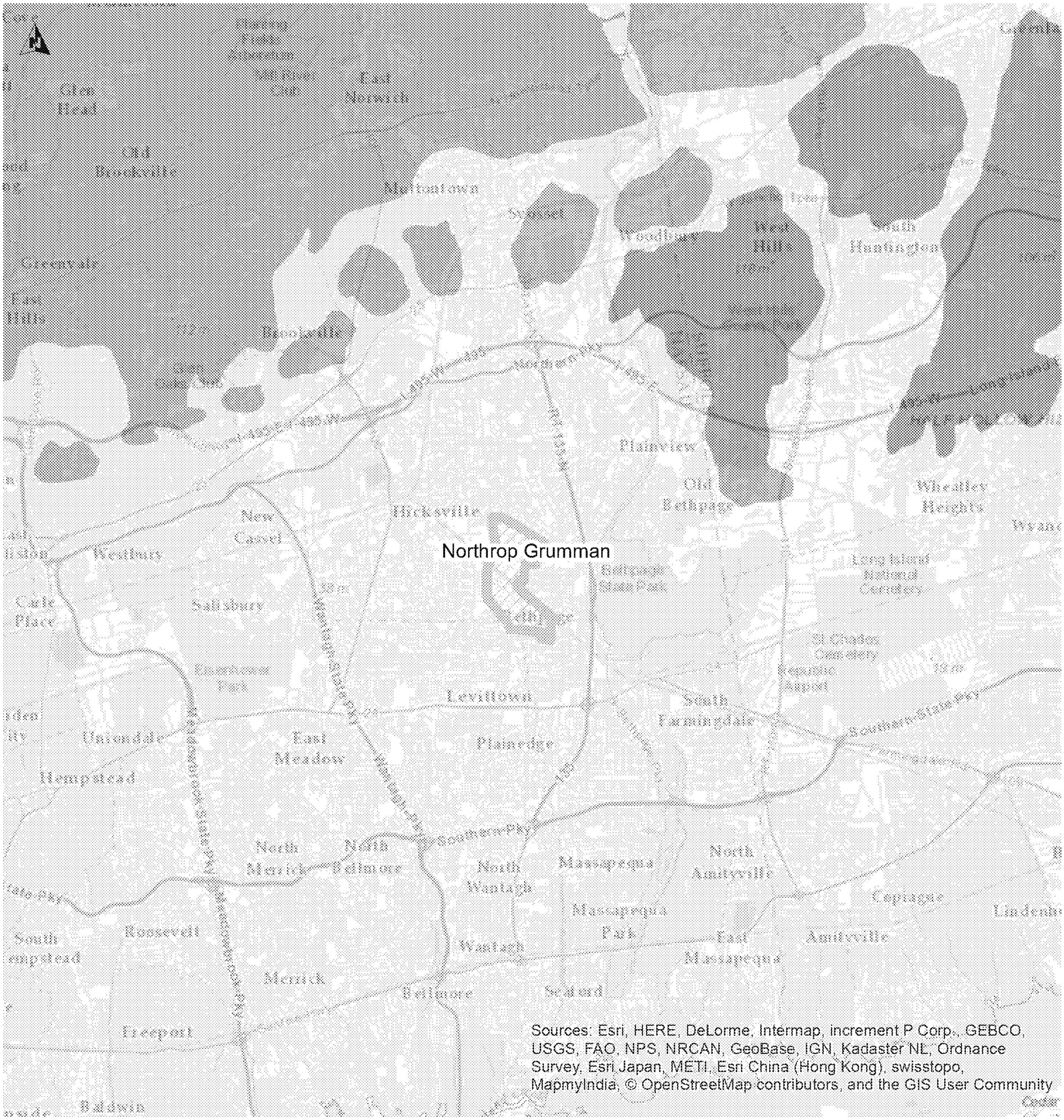
Generalized Hydrogeologic Cross-Section

NYSDEC Site #130003

Figure 1-4

(Remedial Options Report)

Z:\D007625 NYSDEC Standby Contract\Work Assignment Folders\WA#23 Grumman\Memo Figures and Attachments\InkScape Documents\Figure_1-4_Generalized_Hydrogeologic_Cross_Section_20151011.svg



LEGEND

Kame Moraine	Fill	Outcrops and Non-Glacial	Till
Beach	Kame and Ice Contact	Outwash Sand and Gravel	Water
Deltaic and Lacustrine	Morainic	Swamp	Northrop Grumman

0 Miles 3.5

Geologic Data Source: NYS GIS Clearinghouse

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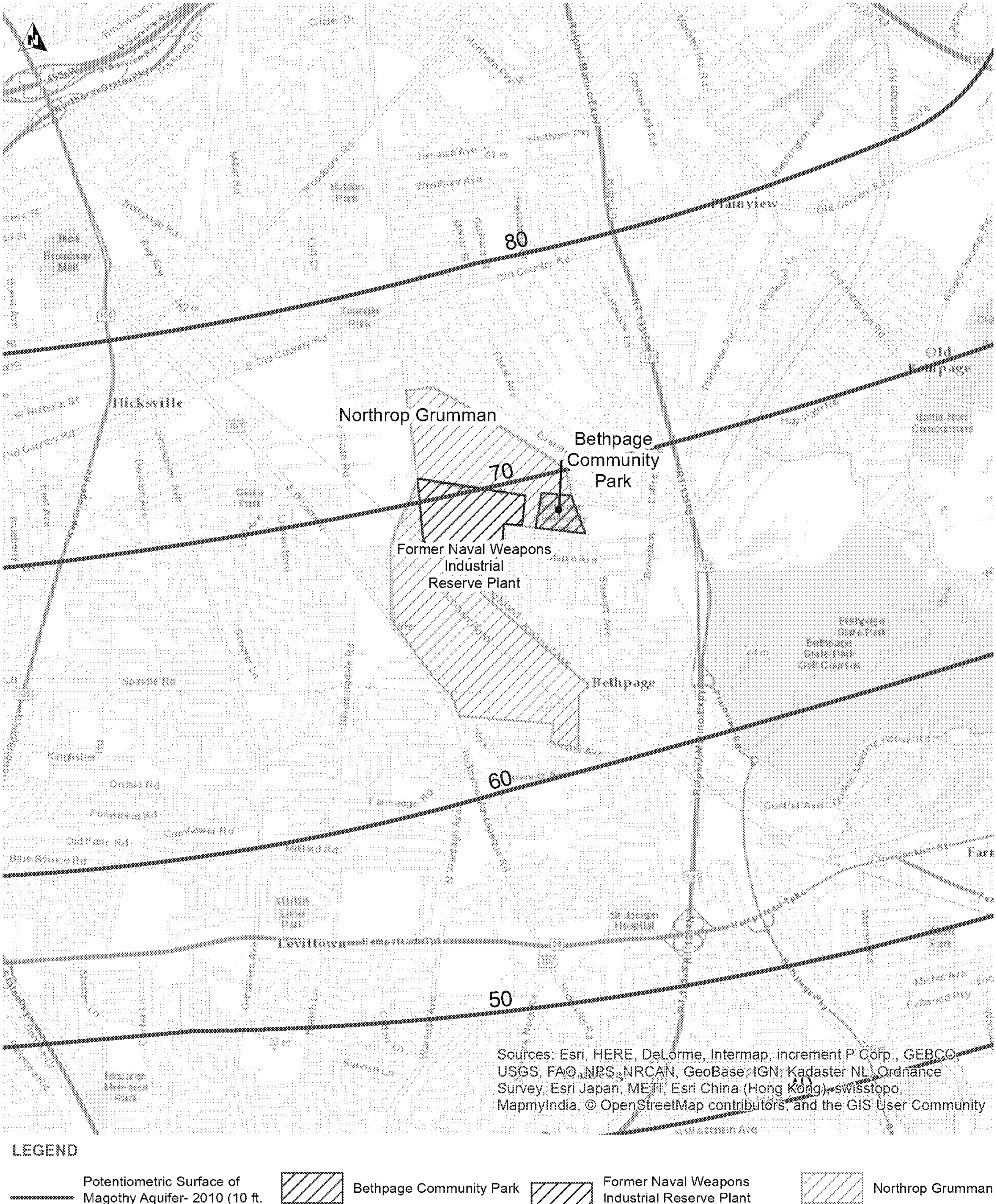
Surficial Geology
NYSDEC Site# 130003
Figure 1-5

PATH: Z:\2015_NEW YORK STATE DEPT OF ENVIRONMENTAL CON\0256275_NYSDEC_ML_WA_23_NORTHGRUMMAN\GIS\MAP_DOCS\DRAFT\GRUMMAN_SURFICIAL_GEOLOGY_20150930.MXD
(REMEDIAL OPTIONS REPORT)



LEGEND

Potentiometric Surface of Magothy Aquifer- 2010 (10 ft. Contours)

Bethpage Community Park

Former Naval Weapons Industrial Reserve Plant (NWIRP) Bethpage

Northrop Grumman

Data Source: Monti, Jack, Jr., Como, Michael, and Busciolano, Ronald, 2013, Water-table and Potentiometric-surface altitudes in the Upper Glacial, Magothy, and Lloyd aquifers beneath Long Island, New York, April-May 2010: U.S. Geological Survey, Scientific Investigations Map 3270, 4 sheets, scale 1:125,000.

0 Miles 1

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Potentiometric Surface of the Magothy Aquifer

NYSDEC Site# 130003

Figure 1-6

PATH: Z:\2015_NEW YORK STATE DEPT OF ENVIRONMENTAL CON\0256275_NYSDEC_ML_WA_23_NORTHGRUMMAN\GIS\MAP_DOCS\DRAFT\POTENTIOMETRIC_SURFACE_MAGHOTHY_20150105.MXD

(REMEDIAL OPTIONS REPORT)

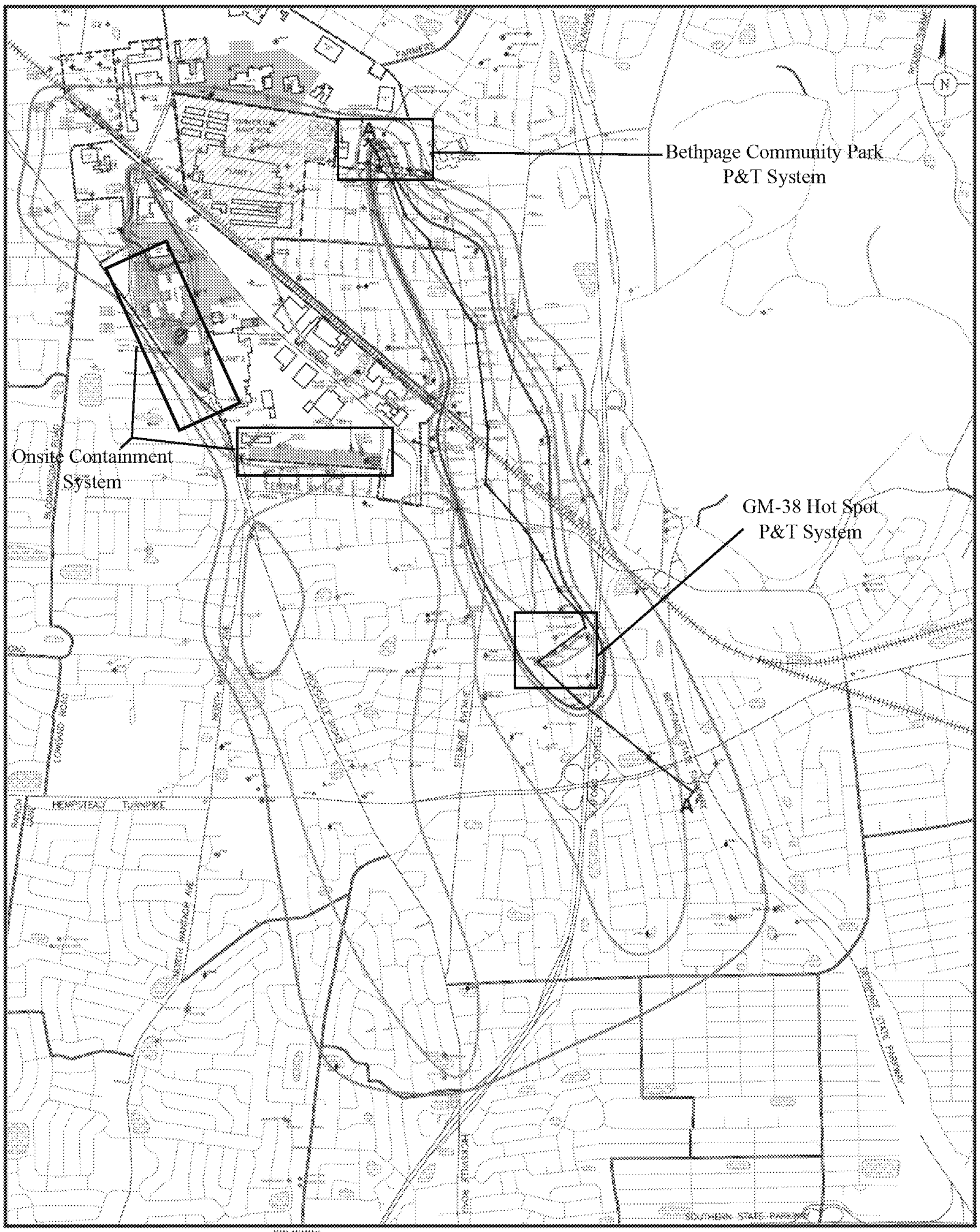

Figure Reference: ARCADIS, 2011, Remedial Investgiation Report (Study Area Groundwater) Operable Unit 3 (Former Grumman Settling Ponds), Bethpage, New York Report. Figure 4.

Additional Data/Information:

☐ Existing Groundwater Treatment Systems

Note:

This figure is originally from ARCADIS (2011) and is presented in the exact format as it was in the original document. No alterations have made to any contour or well data shown above. The only additions are outlines of the ONCT and BCP P&T systems and the GM-38 Hot Spot P&T System.

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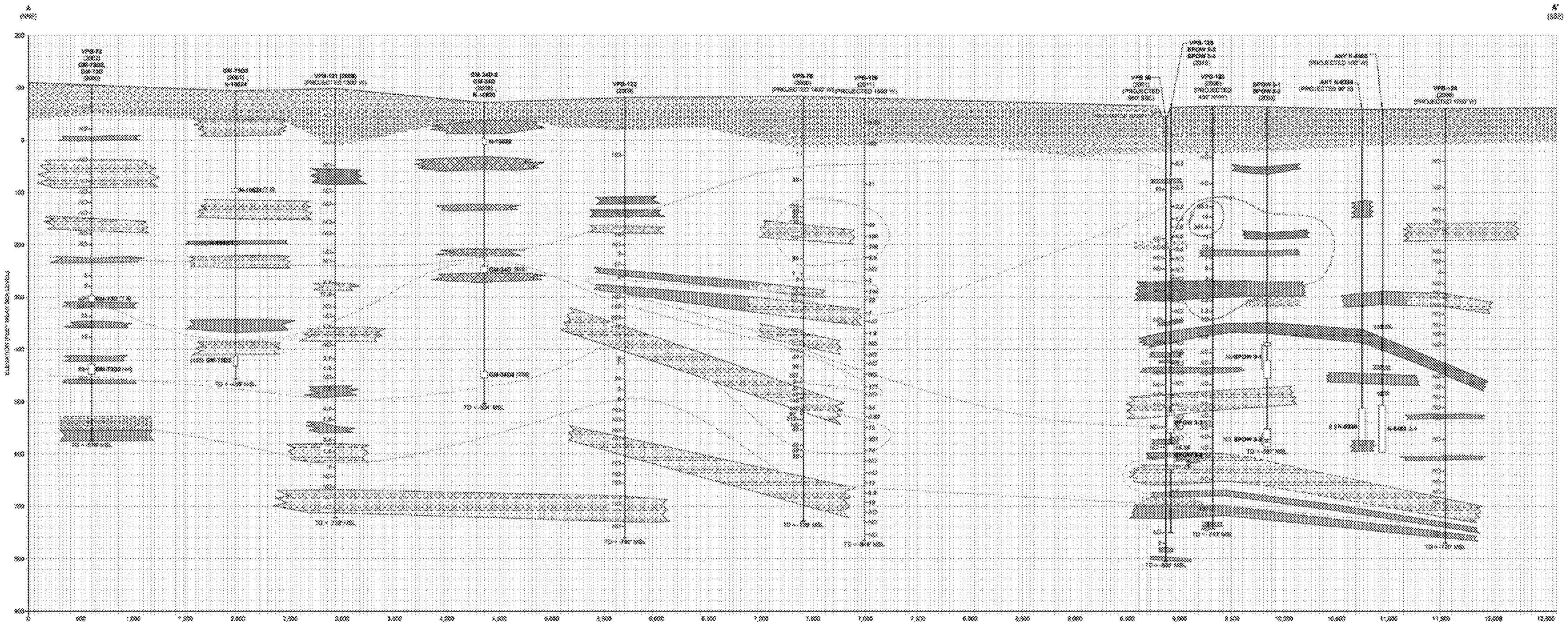
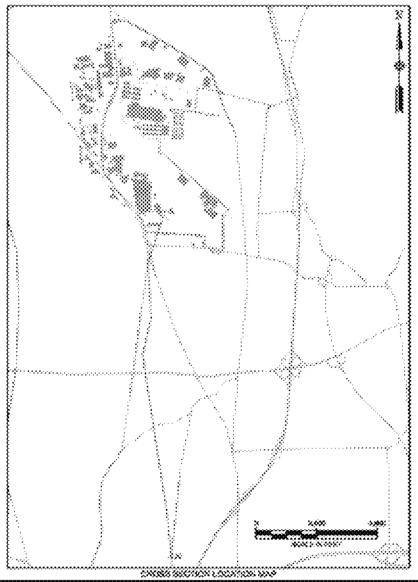
Total Volatile Organic Compounds in Groundwater from ARCADIS (2011)

NYSDEC Site #130003

Figure 1-7

(Remedial Options Report)





Note:

This figure is originally from Tetra Tech (2012) and is presented in the exact format as it was in the original document. No alterations have been made to any contour or well data shown.

Source:

Tetra Tech, 2012, Study of Alternatives for Management of Impacted Groundwater at Bethpage, Naval Facilities Engineering Command Mid-Atlantic.

LEGEND

SAND AND GRAVEL
F-M SAND WITH VARYING AMOUNTS OF SILT, CLAY, AND C. SAND

CONFINING UNITS

INTERBEDDED CLAY AND SAND
SANDY CLAY
CLAY
CONFINING UNIT FROM ARCADIS CROSS-SECTION, NO SPECIFIC LITHOLOGY GIVEN
ARCADIS CROSS SECTION (2004)
TVOC DATA FROM ARCADIS

BPOW 3-2 — MONITORING WELL ID
(2003) — INSTALLATION YEAR
(PROJECTED 450' ESE) — PROJECTION
CONFINING UNIT (DASHED WHERE INFERRED)
MONITORING WELL SCREEN
374 — VERTICAL PROFILE BORING TVOC RESULTS IN ug/L
ND — NOT DETECTED
TOTAL VOC PLUME CONTOUR LINE
PCE PLUME CONTOUR LINE
TD = -743' MSL — TOTAL DEPTH (MEAN) SEA LEVEL

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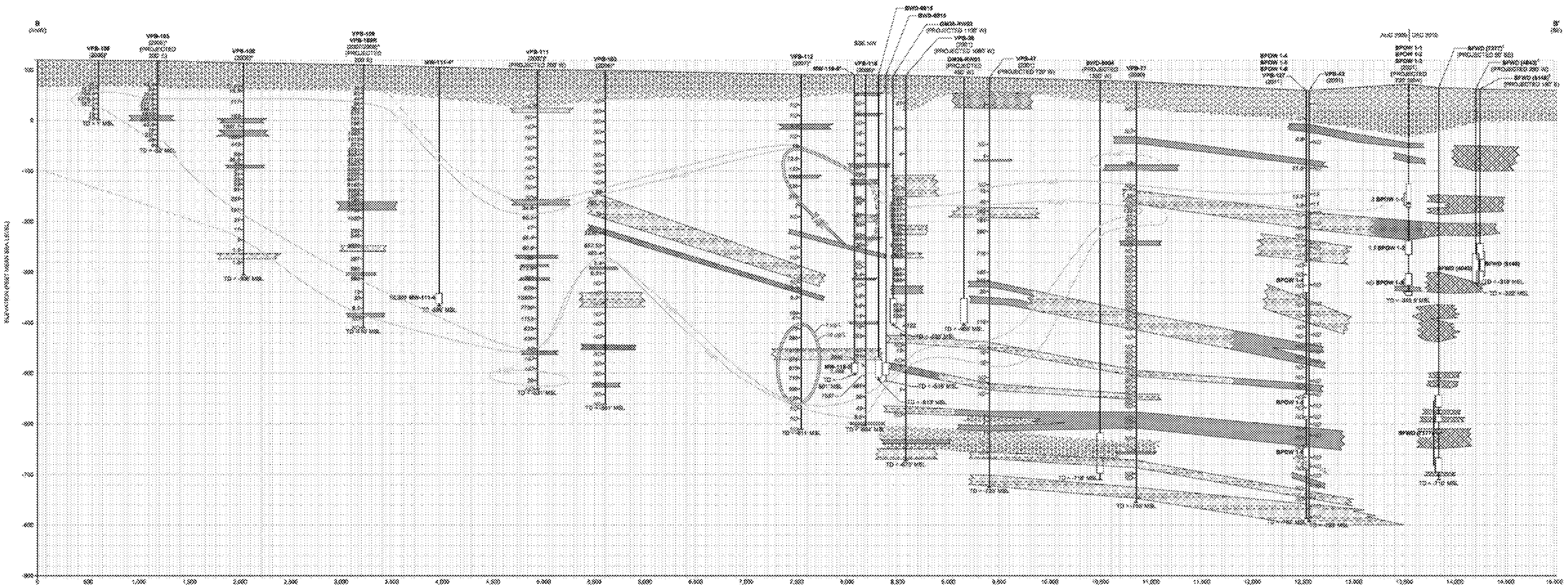
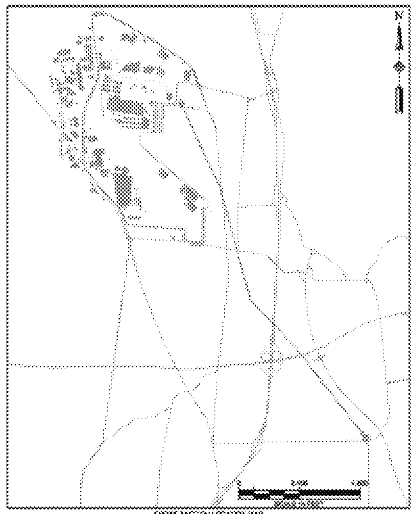
Cross-Section through the Western Plume

NYSDEC Site #130003

Figure 1-8

(Remedial Options Report)



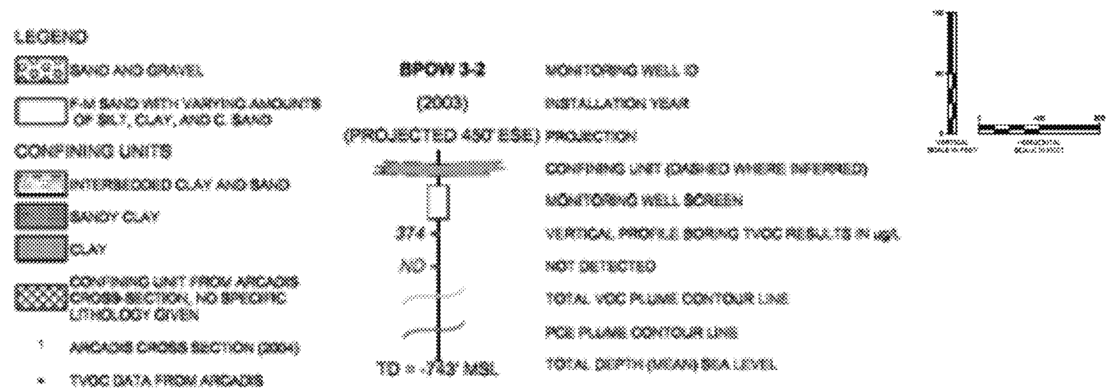


Note:

This figure is originally from Tetra Tech (2012) and is presented in the exact format as it was in the original document. No alterations have been made to any contour or well data shown.

Source:

Tetra Tech, 2012, Study of Alternatives for Management of Impacted Groundwater at Bethpage, Naval Facilities Engineering Command Mid-Atlantic.



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Cross-Section through the Eastern Plume

NYSDEC Site# 130003

Figure 1-9

(Remedial Options Report)

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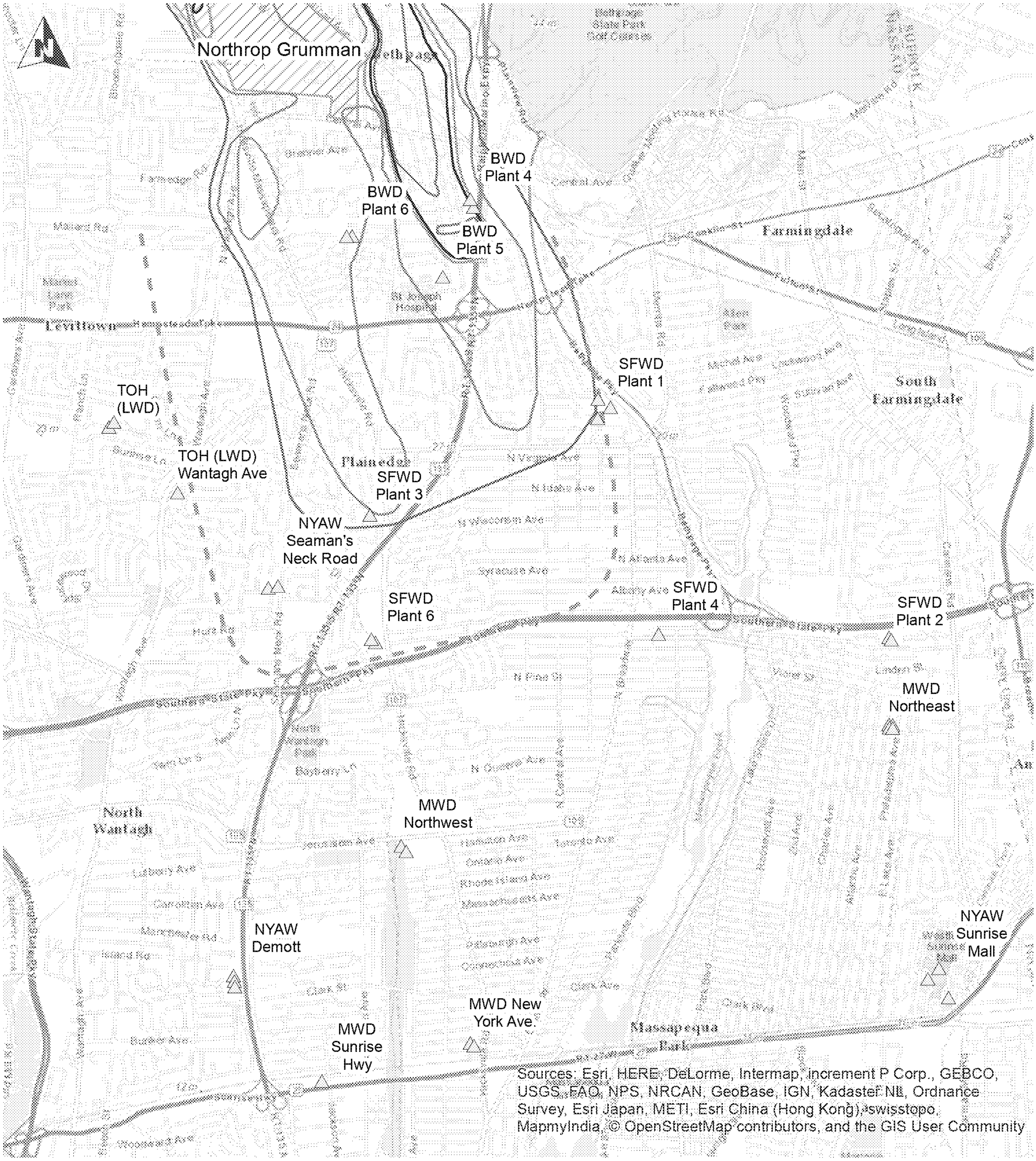

LEGEND

- VOCs Above MCLs (2015)
- Municipal Water Supply Wells and Plant Sites
- Northrop Grumman
- TVOC - 5 ug/l
- TVOC - 50 ug/l
- TVOC - 500 ug/l
- TVOC - 1000 ug/l
- TVOC - 5000 ug/l

Municipal Water Suppliers

NYAW -	New York American Water Co.
BWD -	Bethpage Water District
MWD -	Massapequa Water District
SFWD -	South Farmingdale Water District
TOH(LWD) -	Town of Hempstead Levittown Water District

0 Miles 1

Source:
Massapequa Water District Case In Opposition to NYSDEC NAVY ROD OU-2, February 2011.

Tetra Tech, 2012, Study of Alternatives for Management of Impacted Groundwater at Bethpage, Naval Facilities Engineering Command Mid-Atlantic.

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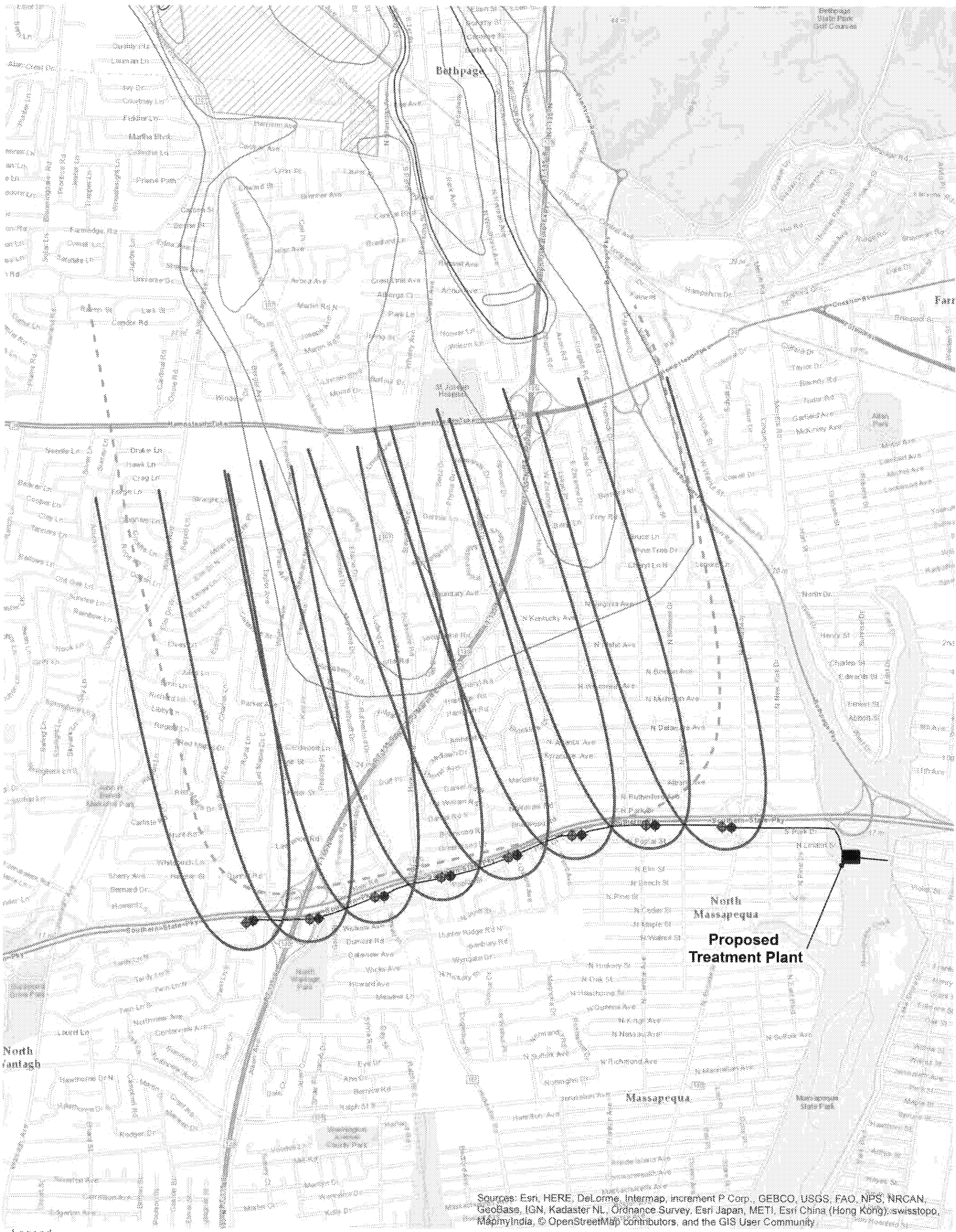
Potential Municipal Well Receptors

NYSDEC Site# 130003

Figure 1-11

PATH: Z:\2015_NEW YORK STATE DEPT OF ENVIRONMENTAL CON\0256275_NYSDEC_ML_WA_23_NORTHGRUMMAN\GIS\MAP_DOCS\DRAFT\GRUMMAN_WATER_SUPPLY_WELLS_20160115.MXD

(REMEDIAL OPTIONS REPORT)



Legend

- Proposed Deep Groundwater Extraction Wells
- Proposed Shallow Groundwater Extraction Wells
- Proposed Treatment Plant
- Extraction Well Conveyance Piping
- Shallow and Deep Groundwater Capture Zones
- VOCs Above MCLs
- TVOC - 5 ug/l
- TVOC - 50 ug/l
- TVOC - 500 ug/l
- TVOC - 1000 ug/l
- TVOC - 5000 ug/l
- Northrop Grumman

0 Miles 0.5

Note:

(1) Plan view of capture zones for both shallow and deep wells.

(2) TVOC contour data from ARCADIS, 2011, Remedial Investigation Report (Study Area Groundwater) Operable Unit 3, (Former Grumman Settling Ponds), Bethpage, New York, Report. Figure 4.

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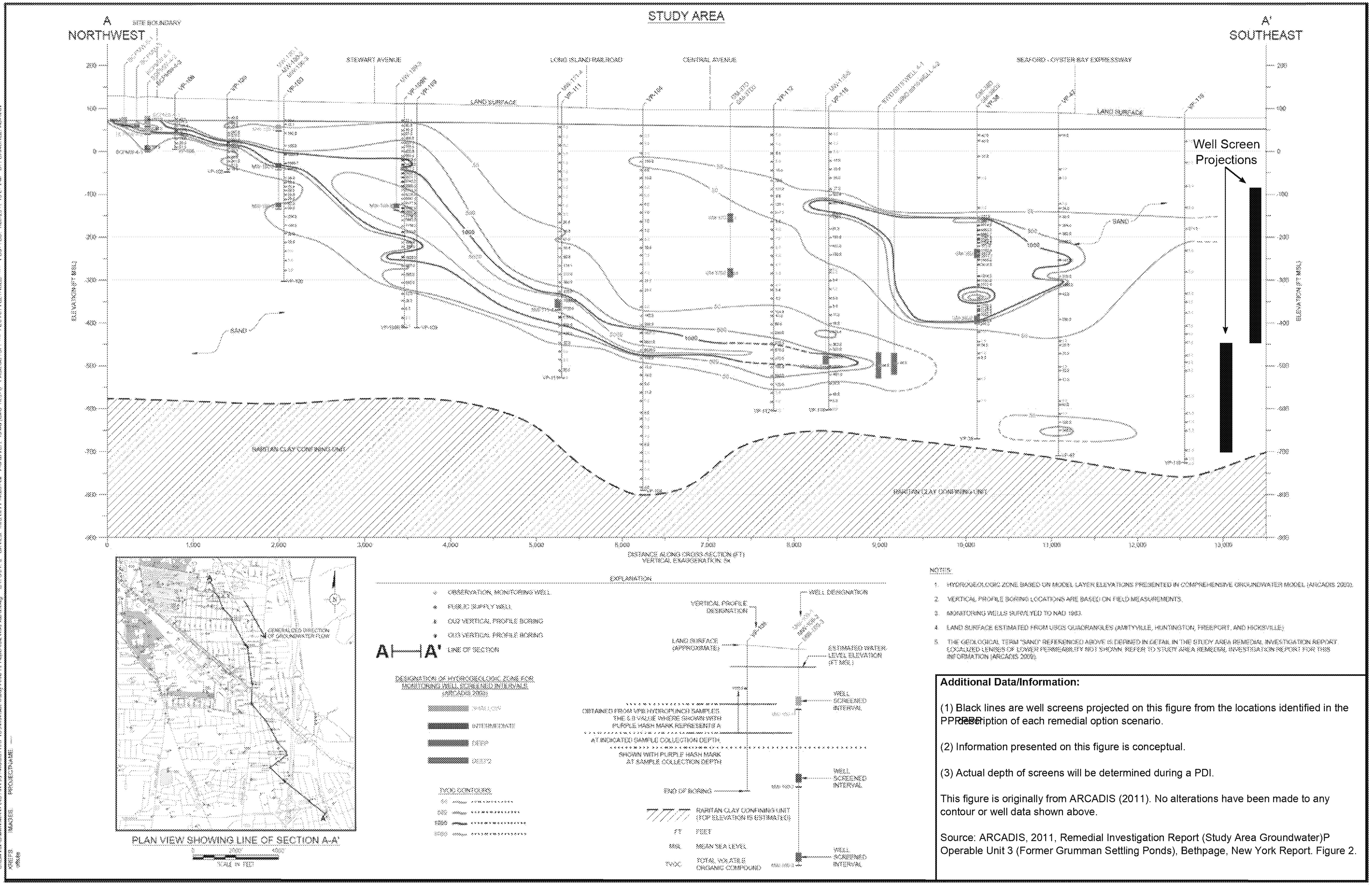
Remedial Option No. 1 - Shallow and Deep Groundwater Capture Zones

NYSDEC Site #130003

Figure 4-1

(REMEDIAL OPTIONS REPORT)



Additional Data/Information:

(1) Black lines are well screens projected on this figure from the locations identified in the PPRPdescription of each remedial option scenario.

(2) Information presented on this figure is conceptual.

(3) Actual depth of screens will be determined during a PDI.

This figure is originally from ARCADIS (2011). No alterations have been made to any contour or well data shown above.

Source: ARCADIS, 2011, Remedial Investigation Report (Study Area Groundwater)P Operable Unit 3 (Former Grumman Settling Ponds), Bethpage, New York Report. Figure 2.

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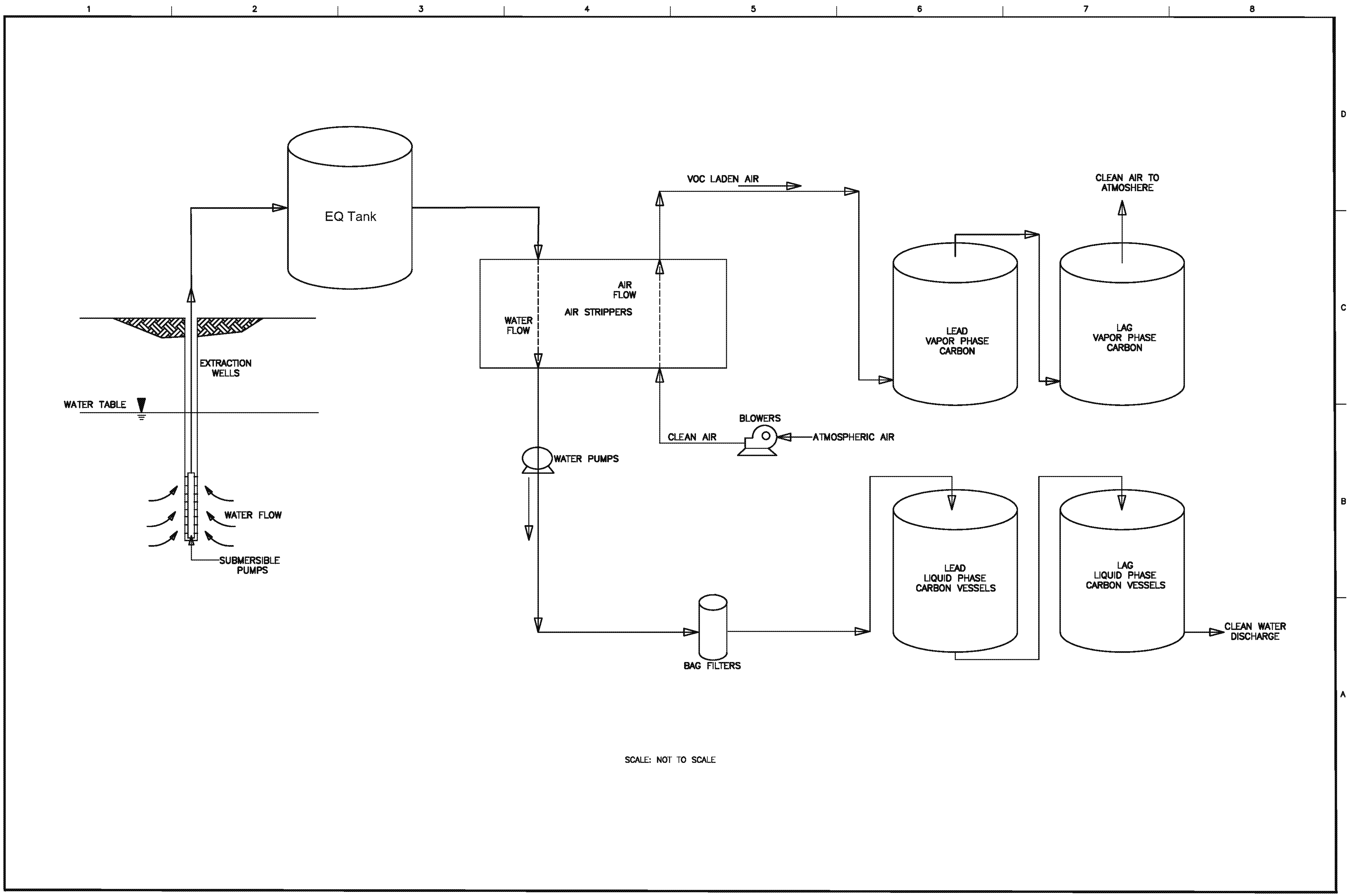
Cross-Section View of Remedial Options

NYSDEC Site #130003

Figure 4-2

(Remedial Options Report)



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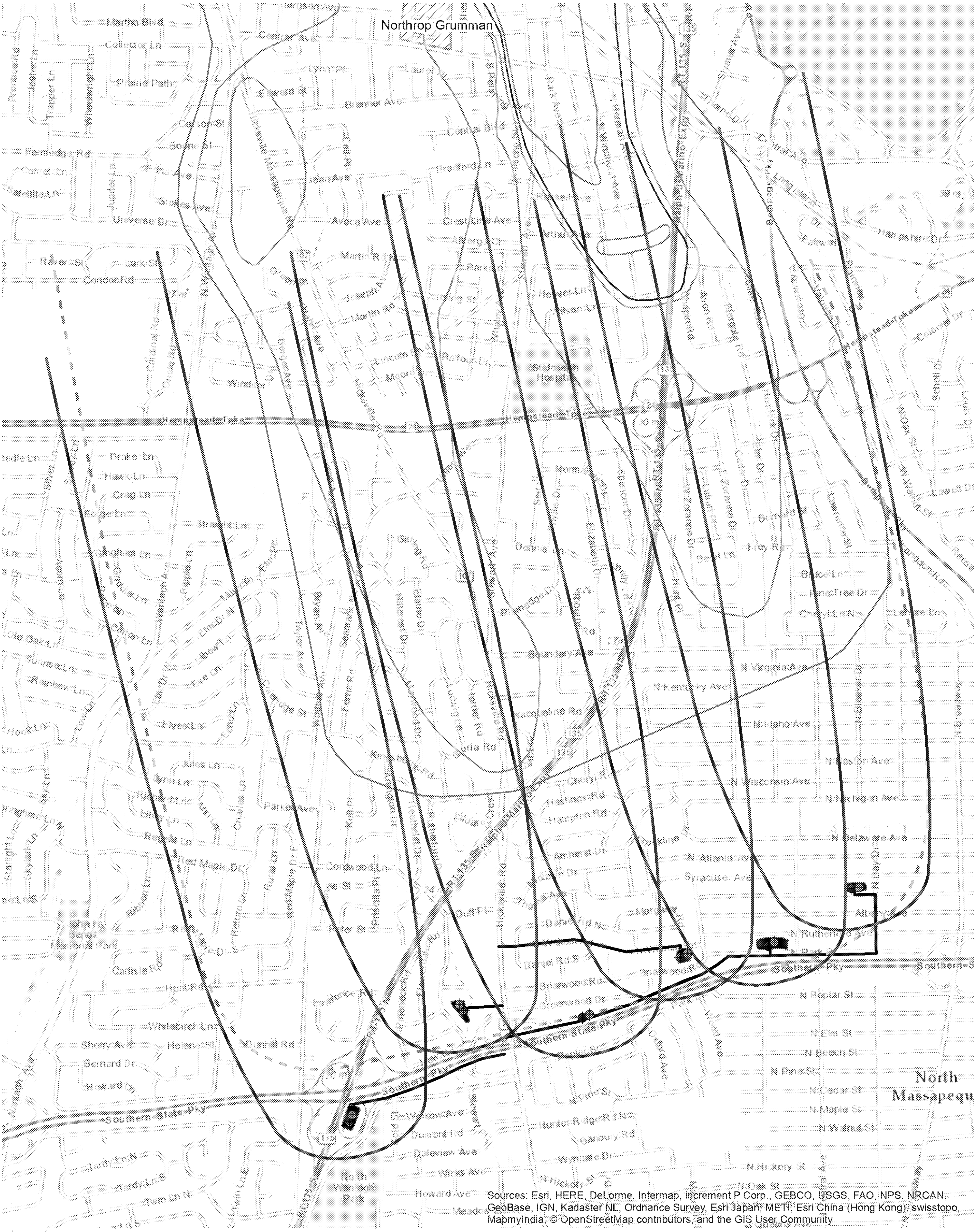
Centralized Water Treatment - System Process Schematic

NYSDEC Site# 130003

Figure 4-3

(Remedial Options Report)



Legend

- Proposed Deep Groundwater Extraction Wells
- Proposed Shallow Groundwater Extraction Wells
- Extraction Well Conveyance Piping to Sewer Truck Main
- Shallow and Deep Groundwater Capture Zones
- VOCs Above MCLs
- Nassau County Recharge Basins
- TVOC - 5 ug/l
- TVOC - 50 ug/l
- TVOC - 500 ug/l
- TVOC - 1000 ug/l
- TVOC - 5000 ug/l
- Northrop Grumman

Note:

(1) Plan view of capture zones for shallow and deep wells.

(2) Extraction well piping connects each well cluster to the 54-inch trunk main.

(3) TVOC contour data from ARCADIS, 2011, Remedial Investigation Report (Study Area Groundwater) Operable Unit 3, (Former Grumman Settling Ponds), Bethpage, New York, Report. Figure 4.

0 Miles 0.5

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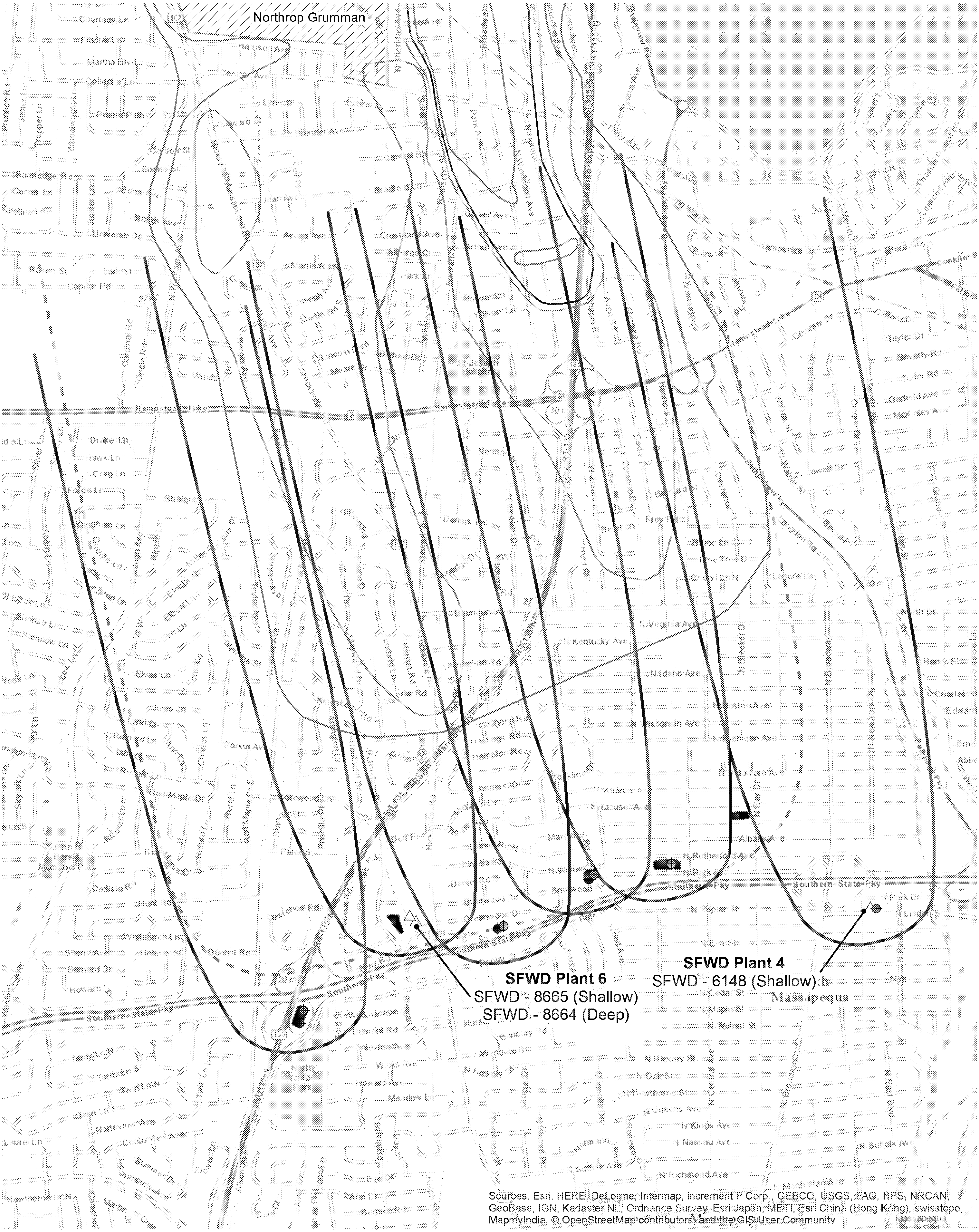
Remedial Option No. 2 - Shallow and Deep Groundwater Capture Zones

NYSDEC Site #130003

Figure 4-4

PATH: Z:\2015_NEW YORK STATE DEPT OF ENVIRONMENTAL CON\0256276_NYSDEC_MI_WA_23_NORTHGRUMMAN\GIS\MAP_DOCS\DRAFT\GRUMMAN_REMEDIAL_OPTION_2_SHALLOW_DEEP_20160204.MXD - USER: JUSTARR - DATE: 2/4/2016

(REMEDIAL OPTIONS REPORT)



LEGEND

- Proposed Deep Groundwater Extraction Wells
- Proposed Shallow Groundwater Extraction Wells
- Extraction Well Groundwater Capture Zone
- VOCs Above MCLs
- Munincipal Water Supply Wells
- Nassau County Recharge Basins
- TVOC - 5 ug/l
- TVOC - 50 ug/l
- TVOC - 500 ug/l
- TVOC - 1000 ug/l
- TVOC - 5000 ug/l
- Northrop Grumman

Note:

(1) Plan view of capture zones for shallow and deep wells.

(2) TVOC contour data from ARCADIS, 2011, Remedial Investigation Report (Study Area Groundwater) Operable Unit 3, (Former Grumman Settling Ponds), Bethpage, New York, Report. Figure 4.

(3) SFWD Plant Location from Tetra Tech, 2012, Study of Alternatives for Management of Impacted Groundwater at Bethpage, Naval Facilities Engineering Command Mid-Atlantic.

Munincipal Water Supplier

SFWD - South Farmingdale Water District

0 Miles 0.5

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Remedial Option No. 3 - Shallow and Deep Groundwater Capture Zones

NYSDEC Site# 130003

Figure 4-5

(REMEDIAL OPTIONS REPORT)

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APPENDIX A

Evaluation and Screening of General Response Actions and Remedial Action Technologies

GENERAL RESPONSE ACTIONS

General Response Actions (GRAs) are broad classes of responses or remedies developed to meet the RAOs. The GRAs consider the nature of the contamination, the contaminants of concern, the physical and hydrogeological characteristics of the Site, and existing Site infrastructure.

Seven GRAs have been identified:

- No Action
- Institutional Controls (ICs) with Long-Term Monitoring (LTM)
- Monitored Natural Attenuation (MNA)
- *In Situ* Treatment
- Containment
- *Ex Situ* Treatment
- Groundwater Disposal Options

No Action

Consideration of a 'No Action' response action is required by the National Contingency Plan (NCP). The No Action response serves as a baseline against which the performance of other GRAs may be compared. Under the No Action response, no remedial actions would be performed to reduce the toxicity, mobility, or volume of contaminated groundwater. No institutional controls would be implemented as part of the No Action GRA.

Institutional Controls with Long-Term Monitoring

Institutional controls are legal or administrative measures designed to prevent or reduce human exposure to hazardous substances. Such measures may include groundwater use restrictions and provision of an alternate water supply. Institutional controls are often implemented in conjunction with other remedy components. Long-term groundwater monitoring is typically completed to demonstrate compliance with the institutional controls.

Monitored Natural Attenuation

This GRA relies on natural mechanisms including dispersion, dilution, adsorption, diffusion, and biodegradation to reduce contaminant concentrations in groundwater. There is no intervention to manipulate the physical, geochemical, or hydrological regime. Comprehensive monitoring is a required component of this GRA to evaluate and verify the progress of MNA, as is a contingency plan that defines the appropriate response action(s) should MNA not achieve the RAOs as expected.

***In Situ* Treatment**

In situ treatment technologies may be used to reduce contaminant concentrations without removal or containment of groundwater. Many *in situ* treatment options are typically applied only for source areas (e.g., thermal treatment, *in situ* chemical oxidation). Other *in situ* treatment options may also be applied at areas of lower contaminant concentrations.

Containment

Groundwater containment is typically achieved using physical vertical barriers, surface caps to limit precipitation infiltration, or hydraulic controls (e.g., interceptor trenches and extraction wells). Containment actions are taken to inhibit further migration of contaminated groundwater by minimizing recharge to the groundwater table and/or altering the groundwater flow direction (i.e., minimizing mobility of contaminants). Containment options typically are not aimed at reducing the volume or toxicity of contaminants; however, containment that involves groundwater extraction and treatment would also result in reducing the volume of contaminants in the aquifer.

Ex Situ Treatment

Ex situ treatment GRAs are typically paired with GRAs involving collection of contaminated groundwater. The goal of *ex situ* treatment is to reduce concentrations of contaminants in groundwater to levels required for the selected discharge process option. *Ex situ* treatment includes technologies that involve biological and physical/chemical processes, as well as transport for off-site treatment.

Groundwater Disposal Options

Groundwater disposal GRAs are typically paired with GRAs involving collection of contaminated groundwater. Extracted groundwater could be transported to a permitted Resource Conservation and Recovery Act (RCRA) treatment/storage/disposal facility (TSDF) or discharged to a publicly owned treatment works (POTW) for treatment. Alternatively, the groundwater could be treated on-Site using *ex situ* treatment and then discharged to a POTW, to a nearby surface water body, or released into the subsurface via surface basins or injection wells.

Sources and Methods for Identification of Potentially Applicable Technologies

Several databases, guidance documents, and journal articles addressing groundwater remediation were used to identify potentially applicable remedial technologies. The following sources are of particular note:

- Federal Remediation Technologies Roundtable (FRTR) website (http://www.frtr.gov/matrix2/top_page.html)
- USEPA Hazardous Waste Clean-up Information web site (http://www.clu-in.org/)
- DNAPL Source Reduction: Facing the Challenge (ITRC, April 2002)
- Critical Review of State-of-the-Art In Situ Thermal Technologies for DNAPL Source Zone Treatment (ESTCP, 2010)

- Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Ground Water at CERCLA Sites (USEPA, 1996)

Technology Identification and Technical Implementability

The following sub-sections describe the technology classes and process options that encompass the means for achieving the GRAs. For example, *in situ* treatment is a GRA that may achieve RAOs using thermal treatment, *in situ* chemical oxidation (ISCO), or biological remediation technologies. Specific process options were identified within each technology class. For instance, ISCO, which is a technology class, includes process options related to the type of oxidant selected, such as permanganate, hydrogen peroxide, or sodium persulfate. Applicable process options were selected based on an understanding of the characteristics of the contaminated media and the technologies that are available to address the media.

The universe of potentially applicable technology types and process options was reduced by screening the technologies and process options with respect to technical feasibility. This was accomplished by using the site information regarding the site geology and contaminant concentrations and distribution. The major factors that influence the technical feasibility of remedial technologies are the geologic complexity, aquifer heterogeneity, depth of contamination and the residential and commercial density of the area. Table 3-1 lists the identified technologies and process options and summarizes the outcome of the technical implementability screening. Results of the preliminary screening of technologies and process options identified for each GRA are discussed below.

GRA: No Action

Under the No Action response, no remedial actions would be completed to reduce the toxicity, mobility, or volume of contaminated groundwater. No institutional controls would be implemented as part of the No Action GRA. This GRA does not fulfill the goals of Chapter 543 of the Laws of 2014, Grumman Plume Review. Therefore, no action will not be retained for further evaluation.

GRA: Institutional Controls and Long-Term Monitoring

The remedial technology identified under the Institutional Controls and Long-Term Monitoring GRA consists of administrative restrictions focused on minimizing potential contact with contaminated groundwater. This GRA also includes long-term monitoring of groundwater to demonstrate the effectiveness of groundwater remediation and compliance with the institutional controls. This process option could be combined with other GRAs to achieve the goals of Chapter 543 of the Laws of 2014, Grumman Plume Review. Therefore, this GRA has been retained for further screening.

GRA: Monitored Natural Attenuation

This GRA relies on natural mechanisms including dispersion, dilution, adsorption, diffusion, and biodegradation to reduce contaminant concentrations in groundwater. There is no intervention to manipulate the physical, geochemical, or hydrological regime with this GRA. The process option associated with MNA consists of long-term monitoring of groundwater quality with existing and/or newly installed wells to verify the progress of MNA. Based on the hydrogeologic conditions, the nature and extent of groundwater contamination, and the fate and transport of contamination, MNA will not reduce the concentration of groundwater contamination to achieve the RAOs before the groundwater reaches a potential receptor (water supply well). Therefore, it was not retained for further evaluation.

GRA: In Situ Treatment

The remedial technologies identified under this GRA consist of measures to treat contaminated groundwater *in situ* (i.e., without removal). The technology classes and associated process options screened under this GRA are described below.

Technology Class: Thermal Treatment

Several thermal treatment technologies are identified that may be applicable.

Steam-Enhanced Extraction: Steam-enhanced extraction (SEE) uses an alternating steam injection and vacuum extraction approach to remove volatile and semi-volatile compounds from the subsurface. The steam injection displaces mobile liquids (groundwater and mobile NAPL) ahead of the advancing steam zone. Liquids displaced by the injected steam are pumped from extraction wells. The vapors containing the volatilized contaminants are captured by vacuum extraction. Once above ground, extracted groundwater and vapors are cooled and condensed. Liquid hydrocarbons are separated from the aqueous steam for recycling, and process vapors and water are treated before discharge.

Several SEE applications have been completed at large sites and below MCL-level groundwater concentrations have been achieved at a few sites. Relatively new thermal treatment schemes involving combinations of SEE with thermal conduction heating (TCH) seek to optimize the use of the lower-energy method (i.e., by enhancing electrical heating projects using steam injection). Given the large area (greater than 5 square miles) and depth (greater than 800 feet) of contamination and the high density commercial/residential area, this technology is not implementable at this site. Therefore, SEE will not be retained for further evaluation.

Electrical Resistance Heating: Electrical resistance heating (ERH) involves installation of electrodes in the subsurface. Soil and groundwater are heated by the passage of electrical current between the electrodes. It is the resistance to the flow of electrical current that results in increased subsurface temperatures. The maximum achievable temperature with ERH is the boiling point of water. As the subsurface is heated, contaminants are volatilized and soil moisture and groundwater are converted to steam. Above ground treatment involves treating vapors, condensate, and entrained water.

Unlike SEE, ERH does not rely on fluid movement to deliver heat. ERH electrodes are constructed using readily available materials (e.g., steel pipe, sheet piling) and have been used to treat contamination to depths of 100 feet bgs (ESTCP, 2010). Over 75 ERH applications have been completed, including several DNAPL applications. Given the large area (greater than 5 square miles) and depth (greater than 800 feet) of contamination, the high density commercial/residential area, and the fact that most of the VOC mass is in the permeable fractions of the aquifer, this technology is not effective or implementable at this site. Therefore, ERH will not be retained for further evaluation.

Thermal Conduction Heating: Thermal conduction heating (TCH), also known as *insitu* thermal desorption (ISTD), is the simultaneous application of heat and vacuum to the subsurface to remove organic contaminants. Heat is applied by installing electrically powered heaters throughout the zone to be treated. The heat moves out into the inter-well regions primarily via thermal conduction. The boiling of fluids in the aquifer matrix leads to steam formation. The steam is captured by the vacuums applied at each heater boring. TCH may be applicable for higher boiling point organics such as PCBs, PAHs, and pesticides because it can heat the subsurface to temperatures exceeding 300 degrees Celsius (°C) assuming that the amount of water in the treatment area can be controlled, because water has a cooling effect on the treatment area. Given the large area (greater than 5 square miles) and depth (greater than 800 feet) of contamination, the high density commercial/residential area, and the fact that most of the VOC mass is in the permeable fractions of the aquifer, this technology is not effective or implementable at this site. Therefore, ISTD will not be retained for further evaluation.

Technology Class: Biological Treatment

Bioremediation is a technology in which the physical, chemical, and biological conditions of a contaminated medium are manipulated to accelerate the natural biodegradation and mineralization processes. Biodegradation is the process whereby microorganisms alter the structure of a chemical, while mineralization is the complete biodegradation of a chemical to carbon dioxide, water, and simple inorganic compounds. In nature, both partial biodegradation and complete mineralization take place; the processes, however, are frequently slow. Biodegradation and mineralization are potentially applicable to VOCs. Heavier, more chemically complex organic compounds tend to be recalcitrant to biodegradation and mineralization (e.g., pesticides, dioxins/furans). Biostimulation and bioaugmentation are two processes used to enhance the rates of biodegradation and mineralization. Biostimulation involves the addition of amendments such as carbon substrates and nutrients to stimulate biodegradation. Bioaugmentation involves the addition of engineered microbes that are known to degrade the contaminants of interest.

Enhanced Reductive Dechlorination via Biostimulation: Reductive dechlorination is the most important process in the natural biodegradation of chlorinated solvents. For reductive dechlorination to completely degrade chlorinated VOCs such as TCE and 1,2-DCE, the geochemical conditions in the subsurface must be ideal and microorganisms that are capable of degrading the chlorinated VOCs must be present. A full-scale approach for enhanced reductive dechlorination (ERD) would involve injection of a carbon substrate to promote achievement of appropriate geochemical conditions in the subsurface and to foster growth of the dechlorinating bacteria. Even though ERD is potentially effective, it is not implementable due to the large area (greater than 5 square miles) and depth (greater than 800 feet) of contamination and the high density commercial/residential nature of the area. This technology could be implemented using a number of cross-sectional fence-type applications; however, it will not achieve the RAOs and goals of Chapter 543 of the Laws of 2014, Grumman Plume Review. Therefore, ERD via biostimulation will not be retained for further evaluation.

Enhanced Reductive Dechlorination via Bioaugmentation: Bioaugmentation involves the addition of non-native organisms known to degrade the contaminants of interest. Bioaugmentation is typically conducted in concert with biostimulation. Bioaugmentation may be used at a site when the presence of an appropriate population of microbes is not present or sufficiently active to stimulate complete degradation. Even though ERD via bioaugmentation is potentially effective, it is not implementable due to the large area (greater than 5 square miles) and depth (greater than 800 feet) of contamination and the high density commercial/residential nature of the area. This technology could be implemented using a number of cross-sectional fence-type applications; however, it will not achieve the RAOs and goals of Chapter 543 of the Laws of 2014, Grumman Plume Review. Therefore, ERD via bioaugmentation will not be retained for further evaluation.

Technology Class: In Situ Chemical Oxidation

In situ chemical oxidation (ISCO) involves the delivery and distribution of oxidants and other amendments into the subsurface to transform COCs into innocuous end products such as carbon dioxide, water, and inorganic compounds. The appropriateness of ISCO technology at a site depends on matching the oxidant and delivery system to the site contaminants and site conditions. For ISCO to be effective, the oxidant must come into direct contact with COCs. The most common oxidants used for ISCO are permanganate, catalyzed hydrogen peroxide (CHP), and activated persulfate. Each of these oxidants was evaluated as a potentially feasible process option.

ISCO with Permanganate: Permanganate is an oxidizing agent with a unique affinity for oxidizing organic compounds with carbon-carbon double bonds (e.g., TCE and 1,2-DCE). There are two forms of permanganate that are used for in-situ chemical oxidation: potassium permanganate ($KMnO_4$) and sodium permanganate ($NaMnO_4$). Potassium permanganate is available as a dry crystalline material while sodium permanganate is a liquid. Permanganate turns bright purple when dissolved in water; this purple color acts as a built-in indicator for unreacted chemical. Reacted permanganate is black or brown, indicating the presence of a manganese dioxide (MnO_2) byproduct.

Compared to the other commonly used oxidants, permanganate is more stable in the subsurface. Unlike CHP, permanganate does not degrade naturally and can persist in the subsurface indefinitely (i.e., it is only consumed by interaction with contaminants or natural organic material). The persistence of permanganate in the subsurface allows for diffusion of the oxidant into the subsurface matrix – making treatment of less permeable materials (i.e., clay or sedimentary rock) possible over time. Even though ISCO with permanganate is potentially effective, it is not implementable due to the large area (greater than 5 square miles) and depth (greater than 800 feet) of contamination and the high density commercial/residential nature of the area. This technology could be implemented using a number of cross-sectional fence-type applications; however, it will not achieve the RAOs and goals of Chapter 543 of the Laws of

2014, Grumman Plume Review. Therefore, ISCO with permanganate will not be retained for further evaluation.

ISCO with CHP: CHP involves the injection of hydrogen peroxide under acidic conditions in the presence of a ferrous iron catalyst to form hydroxyl free radicals. Hydroxyl radicals are very effective and nonspecific oxidizing agents. However, they are unstable and have a fairly short active life (i.e., on the order of hours or a few days). This short active life is not conducive to the longer diffusive time scales required to treat heterogeneous aquifers. Even though ISCO with CHP is potentially effective, it is not implementable due to the large area (greater than 5 square miles) and depth (greater than 800 feet) of contamination and the high density commercial/residential nature of the area. This technology could be implemented using a number of cross-sectional fence-type applications; however, it will not achieve the RAOs and goals of Chapter 543 of the Laws of 2014, Grumman Plume Review. Therefore, ISCO with CHP will not be retained for further evaluation.

ISCO with Activated Persulfate: Sodium persulfate dissociates in water to form the persulfate anion which, although a strong oxidant, is kinetically slow in oxidizing many organic contaminants. When catalyzed or 'activated' in the presence of high pH (e.g., via addition of sodium hydroxide [NaOH]), heat (thermal catalyzation), a ferrous salt, or hydrogen peroxide, the persulfate ion is converted to the sulfate free radical ($SO_4^{\bullet -}$). The sulfate free radical is a very potent oxidizing agent that has a greater oxidation potential and can degrade a wider range of environmental contaminants at faster rates than the persulfate anion. Formation of $SO_4^{\bullet -}$ may also initiate the formation of the hydroxyl free radical, another strong oxidizing agent, as well as a series of radical propagation and termination chain reactions whereby organic compounds may be transformed. Persulfate is an attractive oxidant for DNAPL treatment because it persists in the subsurface, can be injected at high concentrations, and will undergo density-driven and diffusive transport into low-permeability materials. Even though ISCO with activated persulfate is potentially effective, it is not implementable due to the large area (greater than 5 square miles) and depth (greater than 800 feet) of contamination and the high density commercial/residential nature of the area. This technology could be implemented using a number of cross-sectional fence-type applications; however, it will not achieve the RAOs and goals of Chapter 543 of the Laws of 2014, Grumman Plume Review. Therefore, ISCO with activated persulfate will not be retained for further evaluation.

Technology Class: Permeable Reactive Barriers

Permeable reactive barriers (PRBs) are installed across the flow path of a contaminant plume, allowing the water portion of the plume to passively move through the wall. These barriers allow the passage of water while inhibiting the movement of contaminants by employing such reactive agents as zero-valent metals, chelators (ligands selected for their specificity for a given metal), sorbents, microbes, and other reactive media. The majority of installed PRBs use zero-valent iron (ZVI) as the reactive medium for the treatment of chlorinated ethenes. As the iron is oxidized, a chlorine atom is removed from the chlorinated ethene by one or more reductive dechlorination mechanisms, using electrons supplied by the oxidation of iron. The iron granules are dissolved by the process, but the metal disappears so slowly that the remediation barriers can be expected to remain effective for many years, possibly even decades. PRBs are generally intended for long-term operation to control migration of contaminants in groundwater. Granular ZVI and nano-scale ZVI were evaluated as process options for PRBs.

PRB using Granular ZVI: The granular iron used in most PRB applications comprises a mixture of ductile and cast iron cuttings obtained from a number of primary industries that use iron in the production of automotive and related industrial parts. A number of these "feedstocks" are mixed together, put through a rotary kiln in the presence of proprietary gas mixtures, cooled, milled, and sorted to a specific grain size range. Higher grain sizes are used for PRBs constructed using excavation methods where the ZVI is placed directly into a trench. Smaller grain sizes are used for PRBs constructed using injection technologies (e.g., hydraulic fracturing, high-pressure jetting, or liquid atomized injection). Even though PRB using granular ZVI is potentially effective, it is not implementable due to the depth (greater than 800 feet) of contamination and the high density commercial/residential nature of the area. Therefore, PRB using granular ZVI will not be retained for further evaluation.

PRB using Nano-Scale ZVI: Nano-scale ZVI is composed of sub-micrometer particles of iron metal (typically 10 – 1000 nanometers). Nano-scale ZVI is highly reactive because of its large surface area. Nano-scale ZVI is a developing technology. One of the issues associated with the use of nano-scale ZVI is that the particles have a tendency to agglomerate and settle out of the transport solution. In addition, the particles are denser than water, which also gives them a tendency to settle in solutions. Various techniques have been applied to improve nano-scale ZVI stability in solution: emulsification of the particles; suspension in guar gum, suspension in polymers, and others. Typically, nano-scale ZVI is distributed to the subsurface using injection wells. PRB using Nano-Scale ZVI is not implementable due to the large area (greater than 5 square miles) and depth (greater than 800 feet) of contamination and the high density commercial/residential nature of the area. Therefore, PRB using Nano-Scale ZVI will not be retained for further evaluation.

Technology Class: Enhanced Desorption and Treatment

Enhanced desorption refers to approaches to enhance DNAPL and dissolved mass removal involving the injection and subsequent extraction of chemicals or air. Chemicals may be injected into a system of wells designed to "sweep" the DNAPL zone within the aquifer. The chemical "flood" and the solubilized or mobilized DNAPL is removed through strategically placed extraction wells. The produced liquids are then treated and either disposed or returned to the subsurface. The chemicals used are typically aqueous surfactant solutions or cosolvents (e.g., alcohols). When using surfactants, the process is referred to as Surfactant-Enhanced Aquifer Remediation (SEAR). When co-solvents are used, the technology is referred to as co-solvent flooding. Both technologies lower the interfacial tension between DNAPL and the injected chemical(s). Air sparging involves the injection of air into the aquifer to vaporize contaminants and thus mobilize them into the air stream, which is then extracted and treated at the surface.

Surfactant-Enhanced Aquifer Remediation (SEAR): SEAR involves the preparation of low viscosity surfactant solutions that are pumped through the DNAPL contaminated zone by introduction at injection points and removal from extraction points. Detailed site characterization is necessary to define DNAPL zone boundaries and to understand the hydrostratigraphy of the zones to be flushed to avoid unintended DNAPL migration. Hydraulic continuity between the injection and extraction points is required to recover the mobilized DNAPL and the injectants. SEAR technology is not applicable for these site conditions as DNAPL has not been detected. Therefore, SEAR will not be retained for further evaluation.

Co-Solvent Flooding: Co-solvents, usually alcohols, are chemicals that dissolve in both water and NAPL. In an alcohol flood, the alcohol may partition into both the NAPL and water phases. Partitioning affects the viscosity, density, solubility, and interfacial tension of the NAPL. The physical properties of the NAPL vary with the amount of alcohol available for interaction, and whether the alcohol preferentially dissolves into the NAPL or into the water. Complete miscibility is achievable and results in a pumpable solution that, depending upon the density of the NAPL and the proportions of alcohol and water in the solution, may be more or less dense than water. As with SEAR, the success of cosolvent flooding depends on whether hydraulic continuity is maintained between the injection and extraction points. Even though co-solvent flooding is potentially effective, it is not implementable due to the large area (greater than 5 square miles) and depth (greater than 800 feet) of contamination and the high density commercial/residential nature of the area. Therefore, co-solvent flooding will not be retained for further evaluation.

Air Sparging: Air sparging involves injection of a gas (typically air) under pressure into the saturated zone to volatilize groundwater contaminants. Volatilized vapors migrate into the vadose zone where they are extracted under vacuum, generally by a soil vapor extraction system. Air sparging has been used at many sites to treat chlorinated ethenes, including DNAPL. Successful use of air sparging technology depends on the ability of the system to effectively deliver air to the treatment area and the ability of the subsurface media to transmit the air.

Heterogeneous conditions, limit the effectiveness of this technology because of the preferential flowpaths for the air. Even though air sparging is potentially effective, it is not implementable due to the large area (greater than 5 square miles) and depth (greater than 800 feet) of contamination, the heterogeneous nature of the aquifer, and the high density commercial/residential nature of the area. Therefore, air sparging will not be retained for further evaluation.

GRA: Containment

Containment technologies can mimic source treatment by preventing the migration of contaminants to existing or potential down-gradient receptors. Containment technologies include hydraulic control, caps, and vertical barriers, such as sheet piles or slurry walls. These technologies provide hydraulic containment by preventing the migration of groundwater from a source area. The technology classes and associated process options screened under this GRA are described below.

Technology Class: Hydraulic Control

Extraction Wells: Hydraulic control may be achieved by controlling the direction of groundwater flow with well capture zones, which are points of low hydraulic head to which nearby groundwater flows. When groundwater is pumped from extraction wells, the groundwater potentiometric surface is modified. By optimizing the locations of the extraction wells and adjusting the groundwater pumping rates, a potentiometric surface can be manipulated to capture the contaminated groundwater which prevents groundwater carrying contaminants from migrating to receptors. This technology has been used at many sites and is technically feasible. The water that is extracted typically requires treatment and disposal. Hydraulic control using groundwater extraction wells will be retained for further evaluation.

Interceptor Trenches: Interceptor trenches refer to a wide range of lateral groundwater collection systems from tile-drain systems to deep horizontal well installations. Recent technology advances in trench construction methods, such as continuous trenching equipment, use of biodegradable slurries, geotextiles or plastic shoring materials, and other innovations have led to the more frequent use of interceptor trenches. All of these construction methods involve the installation of a horizontal collection system which intersects a large cross-section of an aquifer. Groundwater is directed to the interceptor trench as a result of a hydraulic head drop maintained across the length of the trench.

The hydraulic head drop can be a result of gravity drainage (as in a traditional French drain) or can be induced by pumping from a collection sump attached to the trench system. Interceptor trenches are typically used in shallow groundwater collection applications in unconsolidated media. This technology is not feasible because the groundwater contamination is over 800 feet deep, well below the practical limit of trenching. Therefore, interceptor trenches will not be retained for further evaluation.

Technology Class: Vertical Barrier

Slurry Wall: Slurry walls consist of a vertically excavated trench that is filled with a low-permeability slurry material. Most slurry walls are constructed of a soil, bentonite, and water mixture. The bentonite slurry is used primarily for wall stabilization during trench excavation. A soil-bentonite backfill material is then placed into the trench (displacing the slurry) to create the cutoff wall. Walls of this composition provide a barrier with low permeability and chemical resistance. Other wall compositions, such as cement/bentonite, pozzolan/bentonite, attapulgite, organically modified bentonite, or slurry/geomembrane composite, may be used if greater structural strength is required or if chemical incompatibilities between bentonite and site contaminants exist. Slurry walls are typically placed at depths up to 100 feet in unconsolidated media and are generally 2 to 4 feet in thickness. This technology is not feasible because the groundwater contamination is over 800 feet deep, well below the practical limit a vertical barrier can be installed. Therefore, slurry walls will not be retained for further evaluation.

Grout Curtain: Another method used to create a vertical barrier to groundwater flow is the installation of a grout curtain. Grouting consists of the injection of one of a variety of special fluids (e.g., epoxy, sodium silicate) or particulate grouts (e.g, Portland cement), into the soil matrix under high pressure. Grouting reduces permeability and increases mechanical strength of the grouted zone. When carried out in a linear pattern, grouting can result in a curtain or wall that can be an effective barrier to groundwater flow. The rate of grout injection and the spacing between the injection wells are critical. If the rate of injection is too slow, premature solidification occurs and if the injection rate is too fast, the formation may be fractured. The advantage of grout curtain emplacement is the ability to inject grout through relatively small diameter drill holes at unlimited depths.

The main disadvantage of using grout curtains is the uncertainty that complete cutoff is attained. Given the groundwater contamination is found over a wide area in a high density commercial/residential area, at depths over 800 ft deep, this technology is not implementable. Therefore, grout curtains will not be retained for further evaluation.

Sheet Piling: Sheet pile cutoff walls are constructed by driving sheet materials, typically steel, through unconsolidated materials with a pile driver or vibratory drivers. Given the groundwater contamination is over 800 feet deep, this technology is not implementable. Therefore, sheet piling will not be retained for further evaluation.

Technology Class: Capping

Capping prevents or reduced infiltration of rainwater to the aquifer. Caps (or covers) which involve installing low-permeability material at the ground surface, are typically constructed of soil and synthetic material, asphalt, or bituminous concrete.

Multimedia Cap: A multimedia cap is typically constructed from low-permeability clay and synthetic membrane covered by soil to minimize groundwater recharge. A multimedia cap is not implementable over a 5 square mile area. Therefore, installation of a multimedia cap will not be retained for further evaluation.

Asphalt or Concrete Cap: This process options involves the installation of a layer of asphalt or a concrete slab to minimize groundwater recharge. An asphalt or concrete cap is not implementable over a 5 square mile area. Therefore, installation of an asphalt or concrete cap will not be retained for further evaluation.

GRA: Ex Situ Treatment

Ex situ treatment may be required when the selected remedy involves groundwater extraction, and when the groundwater requires treatment prior to discharge. Although the technologies used for treating extracted groundwater are important aspects of a remedy, they have little influence on reducing contaminant levels or minimizing contaminant migration. Therefore, the technologies presented in USEPA's *Presumptive Response Strategy and Ex-Situ Treatment Technologies for Contaminated Ground Water at CERCLA Sites* (1996) are evaluated.

These presumptive *ex situ* treatment technologies are well-understood methods that have been used for many years in the treatment of drinking water and/or municipal or industrial wastewater. The presumptive technologies presented below are the technologies retained for the development of remedial alternatives. The presumptive response guidance document serves as the technology screening step (USEPA, 1996) for the *ex situ* treatment component of a remedy.

The presumptive technologies for treatment of extracted groundwater containing dissolved organic contaminants include the following:

- Air stripping
- Granular activated carbon
- Chemical / Ultraviolet (UV) oxidation
- Aerobic biological reactors

The presumptive technologies for treatment of dissolved metals include the following:

- Chemical precipitation
- Ion exchange/adsorption

GRA: Groundwater Disposal Options

Groundwater discharge or disposal would be required if the remedy involved groundwater extraction. The primary options for groundwater disposal include treatment followed by discharge to surface water, aquifer recharge/well injection, irrigation, or transport to an off-Site location (e.g., POTW or RCRA TSDF) for treatment and disposal. These options are described and evaluated below.

Publicly Owned Treatment Works (POTW): This process option involves the direct discharge of untreated extracted groundwater to a local POTW for treatment. The extracted water is directed to a wastewater treatment facility operated by the Ceder Creek Water Pollution Control Plant (CCWPCP). The discharge of untreated groundwater to a POTW will be retained as a process option.

RCRA Treatment/Storage/Disposal Facility: This process option involves the transport of extracted groundwater to a licensed RCRA facility for treatment and/or disposal. This process option is not technically feasible based on the volumes of water anticipated to be extracted for a hydraulic containment remedy. Therefore, this process option will not be retained for further evaluation.

Discharge to Surface Water: This process option involves the discharge of treated groundwater to Massapequa Creek. Selected portions of Massapequa Creek have been designated by the NYSDEC as Class A surface water. The discharge of treated groundwater to a Massapequa Creek will be retained for further evaluation.

Discharge Treated Water to POTW: This process option includes the discharge of treated groundwater to CCWPCP for further treatment and disposal. A discharge approval would need to be obtained from CCWPCP, and the *ex situ* treatment system would need to be designed to meet existing discharge limitations. This process option is technically feasible and will be retained for further evaluation.

Infiltration Basin or Gallery: An infiltration basin allows treated water to seep through the ground surface in a controlled area. An infiltration gallery includes a subsurface network of perforated pipes in trenches that return the treated water below the surface, but above the water table. Even though an infiltration basin would be located either on or in the vicinity of each well, this process option is likely not technically feasible because of the very large groundwater disposal rates and the existing basins would be required to infiltrate the current storm water flow with the addition of this projects discharge. Infiltration basins and galleries, therefore, have not been retained for further evaluation.

Well Injection: This process option involves the use of injection wells to push treated water into geologic formations. Given high disposal rates; the number of wells required to inject high disposal rates; the land required to locate each injection well; the shallow depth to water in this area could affect the potential to inject high disposal rates, and the high O&M costs associated with injection wells, this process option will not be retained for further evaluation.

Irrigation: Irrigation allows treated water to be discharge through the land application or irrigation of vegetation. Given the high disposal rates the average growing season is eight months, and land surface is often frozen or covered by snow during the winter, this process option is not feasible and will not be retained for further evaluation.